"Study on dosimetric methods of Mega Voltage X-rays used in Advanced Radiotherapy Technique."

Synopsis

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Swami Ramanand Teerth Marathwada University, Nanded.

For the registration of the topic for

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Abstract of proposed work plan/problem:

Study on dosimetric methods of Mega Voltage X-rays used in Advanced Radiotherapy Technique.

1. Introduction

Before the discovery of ionising radiation, medical science had very few options to treat malignant and benign diseases. The scenario rapidly changed after the discovery of X-rays was announced by German physicist W.C. Roentgen on 30th November, 1895. The potential benefits of X-rays for diagnostic & therapeutic applications of diseases were recognised soon after the discovery. Within two months, i.e. on 29th January, 1896, the E. H. Grubb Company applied X-rays for the first time in cancer treatment under the guidance of Dr. Ludlam [1]. Thus, a physics discovery was incorporated in the field of radiotherapy. Once the biological effects of X-rays were appreciated, their therapeutic application demanded the development and design of highly advanced radiation generating equipments, dose calculation engines & treatment planning systems. Recent developments in radiotherapy are the result of discoveries and technological innovations that resulted from the multidisciplinary research work in the field of Physics, Electronics, Mechanical Engineering & Computer Science.

The medical linear accelerators (Linacs) are used in radiotherapy to treat broad range of cancer cases with exceptional speed & accuracy. Linacs are equipped with on board imager to bring diagnostic quality imaging before & during the treatment. These Cone Beam Computed Tomography (CBCT) images guides user to precisely deliver radiation to tumour volume while sparing surrounding normal tissues. The use of imaging during radiation therapy to improve the precision and accuracy of treatment delivery is called as Image

Guided Radiotherapy (IGRT). As tumour volume is localized correctly, the dose per fraction to the tumour volume escalated without an increase in toxicity to the patients. Therefore, conventional RT treatment of 20- 40 fractions has been reduced to 1- 5 fractions without compromising the treatment outcome for some of the cancer cases. This has revolutionized the practice of radiotherapy. The approach has an important impact on both the patient and the society as it is associated with cost reduction & facilitates access to radiotherapy for more patients. Delivering a high amount of radiation dose in 1 to 5 fractions to 3-dimensionally localized small target volume is termed as Stereotactic radiosurgery. When it is used to treat the lesions inside of the skull, it is called Stereotactic Radiosurgery (SRS) & when it is used to treat the lesions outside of the skull, it is called Stereotactic Body Radiotherapy (SBRT).

The use of small photon fields is almost a pre-requisite for advanced radiotherapy techniques like SRS/SBRT. However, such fields have inherent characteristics of charge particle disequilibrium and high-dose gradient, making dosimetric measurements challenging. Before the publication of Institute of Physics & Engineering in Medicine (IPEM) Report 103 [2] and Technical Report Series (TRS) No. 483 [3] sponsored by the International Atomic Energy Agency (IAEA) & American Association of Physicist in Medicine (AAPM), there was no national or international guidance on how to perform accurate dosimetry for small static photon fields used in SRS & SBRT treatment technique. Partly due to this lack of recommendations, mistakes in patient treatment have been encountered in clinical practice [4] [5] . The consequences of a dosimetric accident for advanced radiotherapy are severe as compared to a conventional radiotherapy accident [6]. Many studies published in the literature show large discrepancies between the output factors measured in the clinical setting with different types of detectors for a particular beam compared with the actual output factor values [7] [8] [9] . The measured output factors for given photon beam energy were different from their real values because of the selection of the wrong detector for the given field size or

when the phantom used was different from water in terms of radiological properties. Therefore, for implementation of advanced radiotherapy procedures like SRS/SBRT, a stringent Quality Assurance (QA) needs to be followed to deliver accurate dose to the patients.

QA of SRS/SBRT has three aspects: (i) commissioning and testing of the treatment planning and delivery systems, (ii) routine QA of the delivery system, and (iii) patient-specific validation of treatment plans. The first aspect is concerned mainly with the integrity of the TPS & linac. The second one is concerned with the normal operation of the linac. The third one ensures an accurate and safe treatment of a patient.

SRS/SBRT QA requires an advanced understanding of mathematical principles of dose optimization, computer-controlled delivery systems and issues that relate to the dosimetry of small and complex-shaped radiation fields. It also requires understanding of treatment setup, planning and delivery uncertainties, and their impact on patients treated with SRS/SBRT. Therefore, understanding these concepts is also important. Overall, QA for SRS/SBRT is much more complex than QA for conventional radiation therapy.

When it comes to patient-specific QA, the ideal test is to perform in vivo dosimetry and place detectors inside the patient, which does not sound like a desirable solution from the patient point of view. Instead, a patient-specific phantom study is done. In this study the SRS/SBRT plan is first generated with the patient CT scan and then patient-optimized fluences are applied to a CT scan of a water equivalent phantom. The TPS recalculates doses for the phantom geometry. The dosimetry verification compares the calculated and measured doses for the phantom

In implementing this process, it is assumed that if Dose measured / Dose calculated for a phantom agrees within a few percent, then Dose delivered / Dose calculated in a patient

should also agree within a few percent. A bonus feature of this study is that it verifies whether an accelerator and/or MLC controls are behaving properly, at least for the day of the study. Typical techniques used for this verification are

- Film dosimetry;
- Ionization chamber measurement; and/or
- 2D-Array measurements (diode or ion chamber).

There is continuous technology innovation and new detectors being developed by the various manufactures and are commercially available for SRS/SBRT dosimetry. The detector arrays (ion chamber or diode based) are one of the novel dosimetry systems being used for this purpose. Along with the various detectors, various phantoms are commercially available for SRS/SBRT dosimetry. However, all the phantoms have the advantages as well as disadvantages. To summarize, all the detectors and the phantoms have inherent problems associated with it. This study aimed at characterizing these detectors with various available phantoms.

2. Review of Literature and Development in the subject (previous work done in the relevant area):

Stereotactic neurosurgery originated from the pioneering work of Horsley and Clarke, who developed a stereotactic apparatus to study the monkey brain in 1908. Spiegel and Wycis applied this technology to the human brain in 1947, which ultimately lead to the development of multiple stereotactic neurosurgical devices during the 1950s. It was Lars Leksell of Sweden, who envisioned stereotactic radiosurgery. Leksell developed the gamma knife to treat intracranial lesions in a noninvasive fashion. His work stimulated worldwide interest and created the field of stereotactic radiosurgery [10].

In 2008, a new formalism was presented for the dosimetry of small and composite fields by Alfonso et al [11]. This work formed the basis of new international

recommendations for the dosimetry of small and nonstandard treatment fields. This article harmonized research efforts in small field dosimetry, to produce more consistent and more widely usable data. The author emphasised that the paper presents only a framework for small field dosimetry and recommended that the data should not be used for practical implementation.

Simultaneously considerable studies for practical implementation of small fields dosimetry used in SRS/SBRT have been carried out. Indra J Das from New York University, USA extensively studied the radiosurgery dosimetry & have discussed the problems associated with the small field dosimetry. Author studied film dosimeter, diamond detector, scintillation detector & small volume pin point ion chamber for small field dosimetry. Author recommended that the small volume and water equivalent detectors are best suited for small field dosimetry. Looking at the large variations in SRS dosimetry, he suggested that there should be a national protocol to review the dosimetry in small fields [8] [12].

Otto Sauer et al have discussed a variety of detectors & procedures to measure small field output factors. Author proposed to apply a simple linear correction for the energy response of solid state detectors. The author cautioned users to apply correction factor only when the size of detector is less than the field size [13].

P. Franscescon et al evaluated the ability of different dosimeters to correctly measure the dosimetric parameters like Percentage Depth Dose (PDD), Tissue Maximum Ratio (TMR) & Off Axis Ration (OAR). The results of the study suggest that the micro ion chamber should not be used for OAR measurements of small field. Author concluded that detectors that are water equivalent and small compared to the resolution of required data may be ideally suited with minimal perturbation in small fields [14].

P. Galvis et al characterised Plastic Scintillation Detector Exradin W2 for Small Field Dosimetry. She compared the profile measurement with Exradin W2 detector & the Gafchromic film & observed good correlation in the penumbra and umbra regions for very small field size [15].

Y. Akino et al carried out a multi- institutional analysis in Japan to study the inter-institutional variability of small field dosimetry beams among HD 120 MLC users. The study demonstrated large variations in the dosimetric parameters for 5mm square field size. The differences were mainly detector dependent and probably due to measurement errors. The author highlighted the need of careful management for small field dosimetry [16].

R. Kinhikar et al carried out the small field output factor measurements for 10 MV photon beam at Tata Medical Hospital, Mumbai. Author measured dosimetry data (beam-quality $TPR_{20,10}(10)$, cross-calibration, beam-profile, and field-output-factor (F.O.F)) using PTW31006-pinpoint, IBA-CC01 and IBA-EFD-3G diode detectors in nominal field size (F.S) range 0.5cm × 0.5cm to 10cm × 10cm with water and solid water medium using Varian Truebeam linac. The collected data was used to commission Eclipse-Treatment Planning System (TPS). He found 3% agreement between the measured dose & TPS calculated dose for F.S 1.5cm × 1.5cm & above [17]. Limitation of the study is that author did not commented on results for F.S. in the range 0.5cm to 1 cm.

S. Dufreneix et al obtained field output factors for small fields via a large multicentre study in France. This study gathered over 400 measurements performed on 19 different linacs with more than 50 detectors. Author suggested considering these results as a cross verification tool for any radiotherapy centre starting SRS/SBRT program to minimise the systematic errors when determining small field output factors. Limitation of the study was

that mean field output factors were given for nominal field sizes rather than the irradiation field sizes defined by the FWHM (as recommended in the IAEA TRS-483) [18].

S. Menon et al performed a retrospective dosimetric comparison of Monte Carlo & Pensil Beam algorithms in SRS/SRT plans of cranial arteriovenous malformations. The study demonstrated PB algorithm may not be sufficiently accurate to predict dose distributions for small fields where there is loss of LCPE [19] . Author also conducted a study to compare and validate Anisotropic Analytical Algorithm (AAA) and AcurosXB (AXB) algorithms of Eclipse Treatment Planning System (TPS) in RapidArc-based SRS plans of patients with solitary brain metastasis. Author used an in-house developed cylindrical phantom to validate the dose calculated by the TPS using AAA and AXB algorithms against measured dose. Author found superiority of AXB algorithm over AAA [20]. Author studied only two types of tumours i.e. AVM & brainmets for comparison of dose calculation algorithms.

S. Parlar et al investigates the effect of small field output factors (OF) obtained with ion chambers of different volumes on intensity-modulated radiotherapy (IMRT) treatment plans. Three different beam models were created at TPS using small fields OFs measured by ion chambers with three different volumes, i.e. 0.65, 0.13 and 0.04 cc respectively. He observed greatest difference in point-dose measurements made in IMRT plans produced with beam model build using ion chamber of volume 0.65 cc. Author concluded that appropriate detectors should be used in the measurement of small-field beam data and large-volume ion chambers are not suitable for small-field measurements. Furthermore, detecting inaccurate OF values in quality assurance performed during TPS commissioning depends on the sensitivity of both the designed treatment plan and the dosimetric method used to detect these errors. Therefore, a number of different dosimetric methods recommended by relevant protocols should be used to detect every one of these errors [21].

In brief, the challenges and issues in SRS/SBRT dosimetry are: The clinical applications and limitations of commercially available detectors (Ion Chamber, Film Dosimeter, TLD, MOSFET and diodes), availability of suitable phantoms to carry out dose measurement, the complex shape of the tumors, point dose measurements at central axis and off-axis, choice of ideal detector for planar verification (arrays and films). Therefore, implementation of a successful SRS/SBRT programme demands standard operating procedures for each step involved in SRS/SBRT procedure. Also, QA of each step to ensure the correct delivery of dose during SRS/SBRT procedure.

3. Objective of research/Proposed Hypothesis:

As per International Agency for Research on Cancer (IARC), the global cancer burden in 2020 was raised to 19.3 million new cases and 10 million cancer deaths. To handle such a cancer burden, there has a substantial increase in the number of healthcare facilities equipped with advanced diagnostic & therapeutic machines all across the globe. It resulted in earlier and earlier tumour identification with the smaller lesion. Simultaneously, rapid developments in imaging and radiation-delivery technology like Intensity Modulated Radiotherapy (IMRT) or Volumetric Modulated Arc Therapy (VMAT) have fuelled the application of SRS & SBRT in modern radiotherapy [22].

Many cancer patients will require SRS/SBRT to treat their disease. To meet the growing demand, there is a need for stereotactic radiotherapy procedures to be available in most radiation oncology departments rather than remain confined to specialist centers. This creates a challenge for physicists in departments who do not have SRS/SBRT experience or the necessary equipment, to meet the strict demands on accurate dose delivery for these procedures. Due to technological innovations various radiation detectors & phantoms are available in the market for performing the quality assurance (QA) of SRS/SBRT procedures.

However, these detectors & phantoms are very expensive. Most of the radiotherapy centers in India have limited detectors & phantoms to carry out SRS/SBRT QA. There is no national data availability for physicist on machine QA & Patient Specific (PSQA) tests which needs to be performed for successful implementation of SRS/SBRT procedures. The evaluation of various detectors for SRS/SBRT dosimetry will be a benchmark for the clinical implementation. Therefore, the proposed work is to perform a study on dosimetric methods of Mega Voltage X-rays used in SRS & SBRT with following objectives:

- ***To conduct the national survey of machine & patient-specific Quality Assurance practice (PSQA) for SRS & SBRT keeping following objectives in mind:***
    - ✓ To describe the impact on ongoing quality assurance (QA) and provide guidance on QA practice;
    - ✓ To describe how these processes fit together with each other and provide guidance on the clinical implementation of SRS & SBRT;
    - ✓ To identify areas for potential improvement; and
    - ✓ To ensure the standardisation, consistency, efficacy, & efficiency of PSQA.

- ***To estimate the efficacy of multiple detectors for absolute and relative dosimetry of SRS & SBRT to improve dosimetric accuracy.***
- ***To validate phantoms available for SRS/SBRT dosimetry.***
- ***To standardize the methods for SRS/SBRT dosimetry to simplify and reduce the SRS/SBRT QA workload.***
- ***To study the impact of the choice of radiation detectors used for TPS beam modelling on SRS/SBRT treatment plan quality***.

4. Methodology to be adapted:

An online survey across various cancer centers in India will be conducted to access the current practice of machine QA & PSQA for SRS & SBRT delivery. The survey will be based on a questionnaire addressing the departmental policy & procedure of SRS/SBRT, equipments used for radiation delivery, detectors used for radiation measurements, and treatment/tumour sites selected for SRS/SBRT etc.

The Mega Voltage (MV) X-rays i.e. 6MV, 10MV, 6MV FFF(Flattening Filter Free) & 10MV FFF generated from TrueBeam™ Medical Linear Accelerator (Varian Medical System, Palo Alto, USA) will be studied for small fields with the help of 3D-Scanner™ Sun Nuclear Corporation (SNC) (Fl, USA) radiation Field Analyser (RFA) using various radiation detectors as shown in fig.1 (a) & 1(b). RFA will allow user to collect the dosimetric data like PDD, TMR, OAR, and Output Factor for small field as shown in fig. 2 (a) & fig. 2 (b). The collected dosimetric data will be analysed by Sun Nuclear Dosimetry Software. Then the data will be used to commission the dose calculation algorithms viz. AAA & AXB at Eclipse TPS as shown in fig 3. AAA & AXB will be configured for each detector, so there will be separate algorithm for a detector under study. The AAA/AXB calculates the radiation dose inside the Computed Tomography (CT) images of patient/phantom.

A retrospective study will be performed on CT images of phantom. Multiple treatment plans will be generated using all available algorithms to quantify the effect of choice of detector on dose distribution. These calculated doses will be measured on linac with the help of Phantom. The calculated vs. measured dose will be compared using commercial software like SNC Patient as shown in fig. 4. The procedure will be repeated for various detectors to ensure the best detector and phantom combination for treatment plan verification.

Fig.1 (a) TrueBeam Linac

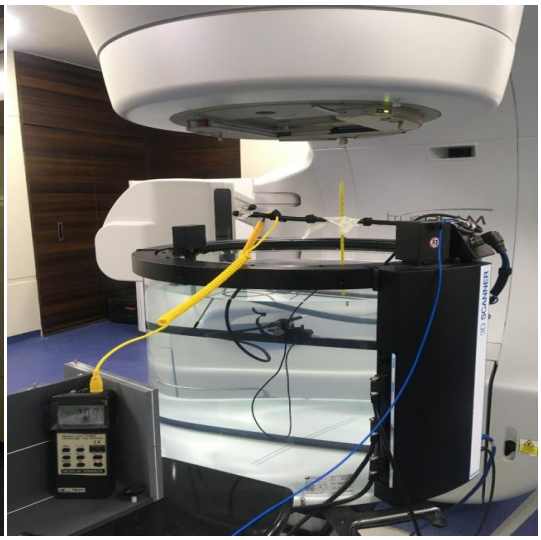

Fig.1 (b) 3D Scanner SNC RFA

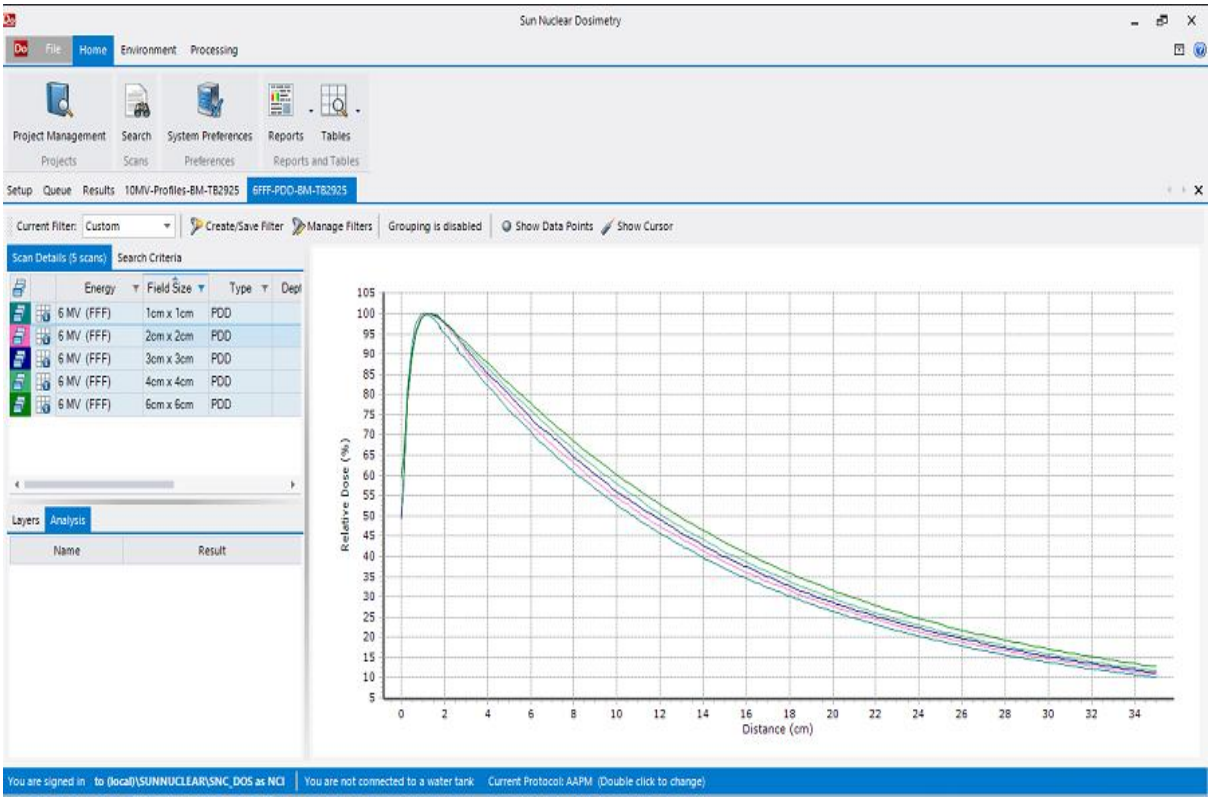

Fig. 2(a) 6MV FFF PDD for F.S. 1cm x 1cm to 6cm x 6cm

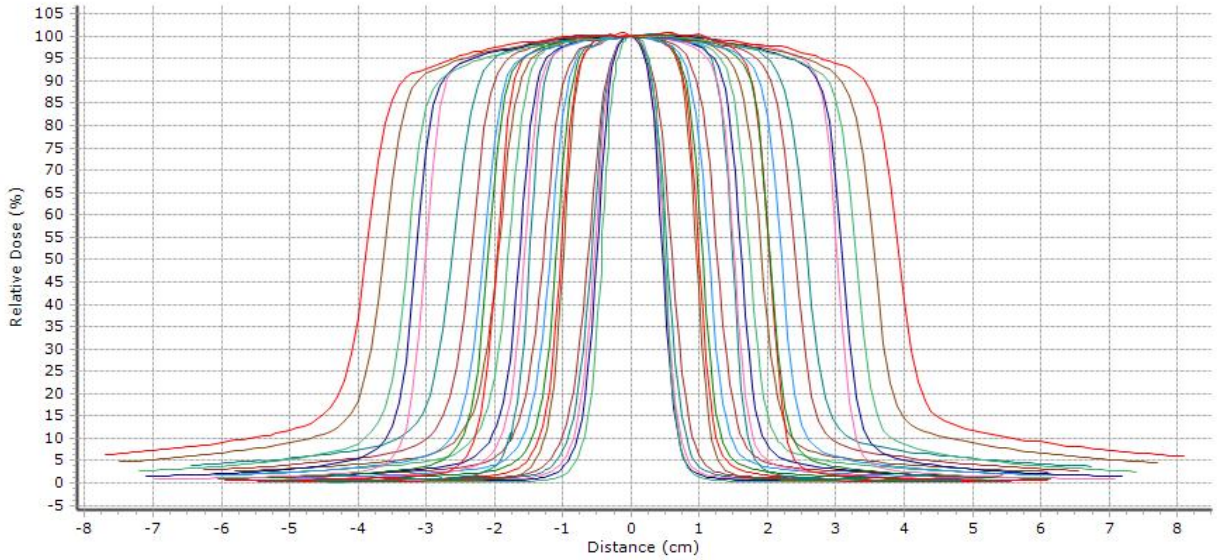

Fig.2(b) 6MV FFF OAR for F.S. 1cm x 1cm to 6cm x 6cm at various depth inside RFA

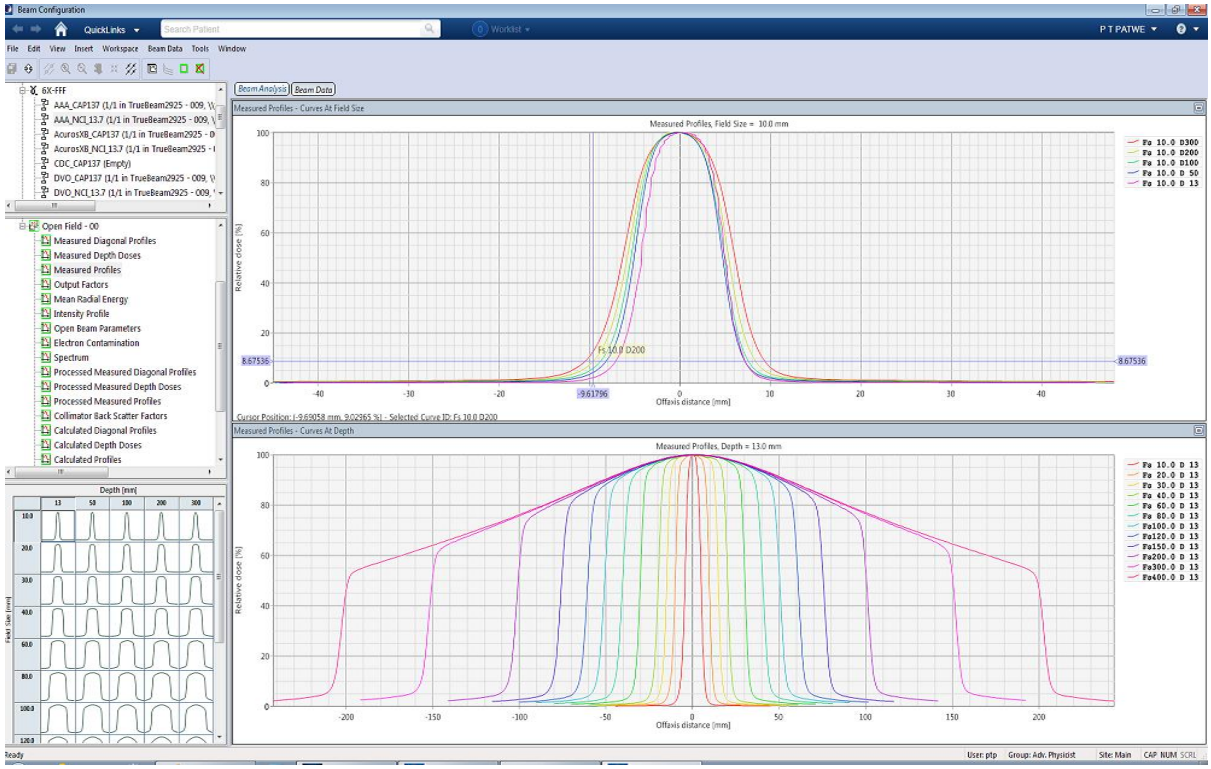

Fig. 3 Screenshot of Beam Configuration window to commission AAA in Eclipse TPS

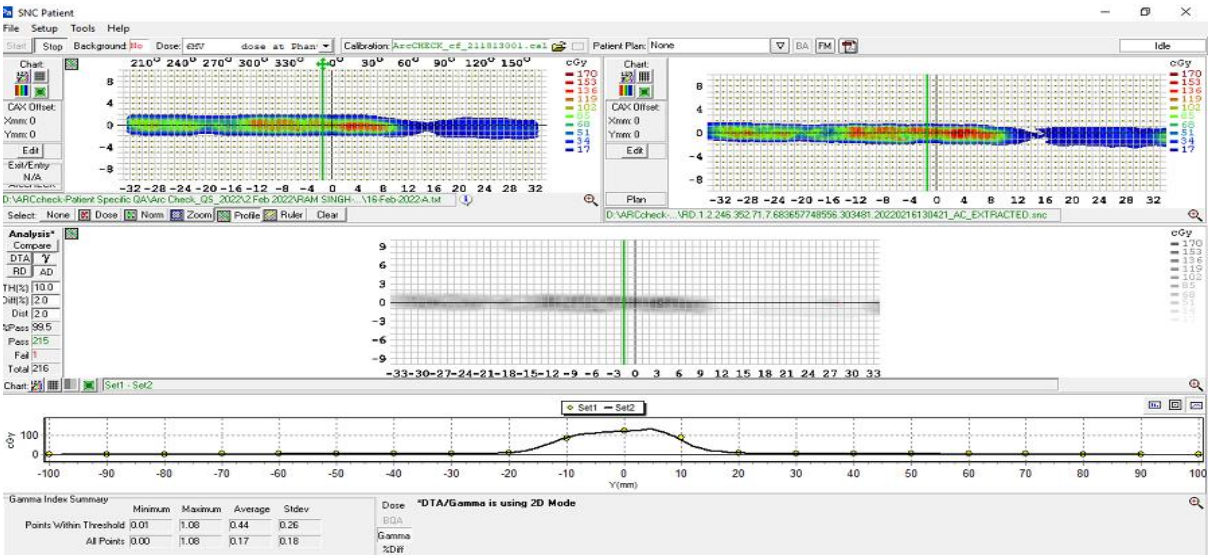
SNC Patient
File Setup Tools Help
Gamma Index Summary
Minimum Maximum Average Stdev
Points Within Threshold 0.01 1.08 0.44 0.26
All Points 0.00 1.08 0.17 0.18
*DTA/Gamma is using 2D Mode

Fig. 4 Screenshot of SNC Patient software to evaluated measured dose against calculated dose.

5. Importance of study/ Society Application:

During the past few years, use of SRS & SBRT procedures has grown rapidly, not only because of academic interest but also because of the significant increase in the cancer cases that call for the fundamental understanding of these specialized procedures.

➢ International/ National Status

The following scientists are actively doing research in this field at the International/ National Level:

i. Indra J Das, New York University, USA

ii. J Seutnjen, McGill University, Montreal, Canada

iii. H Palmans, National Physical Laboratory, Teddington, UK

iv. Otto A Sauer, University of Wuerzburge, Wuerzburge, Germany

v. S D Sharma, Bhabha Atomic Research Centre, Mumbai, India

vi. R Kinhikar, Tata Memorial Hospital, Mumbai, India

vii. S Menon, Regional Cancer Centre, Thiruvananthapuram, India

➢ Significance of the study

i) In India, advanced radiotherapy like SRS/SBRT is the evolving technique to treat some of the cancer types which are benign or malignant in nature. The therapeutic success of this procedure not only relies on the accurate measurement & modelling of small photon beam in TPS but also on the safe delivery of dose to the patient. There aren't any national guidelines or recommendations for the physicist to successfully implement these techniques in a clinical environment so that the patients receive quality treatment. This dissertation aims to create a protocol for safe, effective and accurate delivery of radiation dose to the patients treated with SRS/SBRT technique.

ii) The TPS used for patient dose calculation on CT images is sophisticated & complex. There were many radiotherapy accidents reported for inaccurate dose delivery to the patients during SRS & SBRT. To avoid/lessen the radiotherapy accidents, pre-treatment dose verification on phantom is necessary. The present work is devoted to study megavoltage x-rays viz. 6MV & 10 MV for small fields used in SRS/SBRT. From this work, one can understand the appropriate selection of mega voltage X-ray energy for given treatment site, suitable detectors & phantoms for small field dosimetry. In the present work, different dosimetric methods for SRS/SBRT will be studied to improve accuracy of SRS/SBRT dose delivery.

6. Proposed work Plan/ Formulation and Structure of Study:

Structure of Study	Years			
	0	1	2	3
Course Work, Literature Review, Conducting Survey, Data Collection & Result Analysis				
Publish Data in Conference proceedings and peer reviewed journal				
Dosimetric data collection for various detectors & phantoms, Result Analysis. Publish Data in Conference proceedings and peer reviewed journal				
Preparing Thesis & Defence				

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